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Power Allocation Using Multi-Objective Sum Rate Based Butterfly Optimization Algorithm for NOMA Network

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Abstract: In recent times, non-orthogonal multiple access (NOMA) is a growing technique for the future 5G networks to address the incredible evolution of mobile data traffic and radio access issues based on concurrent communication between multiple users. However, the performance of the NOMA is affected due to an inappropriate power allocation to the users, which affects the system's sum rate. In this research, the multi-objective sum rate-based butterfly optimization algorithm (M-SRBOA) is proposed to address the power allocation challenges of the NOMA network. The M-SRBOA is optimized by considering distinct objective functions like sum rate and Rayleigh fading coefficients. Therefore, the developed M-SRBOA method allocates an appropriate power for all users of the NOMA, which increases higher sum rate. The performance of the M-SRBOA method is analyzed using achievable sum rate and outage probability. The existing researches such as equal power allocation (EPA), optimal power allocation (OPA) factors and difference of convex optimization (DCO) are used to justify the efficiency of the M-SRBOA method. The achievable sum rate of M-SRBOA for the SNR of 15 dB with noise variance of 2 is 13.09 bps/Hz, which is high compared to the EPA, OPA and DCO.

Keywords: Achievable sum rate, Multi-objective sum rate based butterfly optimization algorithm, Non-orthogonal multiple access, Outage probability, Power allocation.

1. Introduction

NOMA is considered a powerful technology in upcoming wireless technology due to its higher spectral efficiency. The utilization of successive interference cancellation (SIC) in the receiver of NOMA is employed to achieve high spectral efficiency and sum-rate than the orthogonal multiple access [1 - 4]. The main criteria of the NOMA are to assist many users in the same resource block, i.e., subcarrier or time slot [5]. The users with worse channel conditions are identified and eliminated using the SIC, which is used to enhance the signal reception [6 - 8]. In NOMA, the data symbols of multiple users are concurrently sent by utilizing the power-domain multiplexing, which made NOMA can easily be combined with the traditional approaches such as device-to-device and cooperative relaying communication [9, 10]. The developed modern Radio access technologies, i.e., NOMA, are used to achieve the heterogeneous requirements that comprise higher throughput, less latency, improved fairness, higher reliability, and massive connections [11].

Multi-carrier NOMA (MC-NOMA) is multiplex numerous users on the same subcarrier by accomplishing the superposition of signals on the transmitter side. Then interference among the superposed signals is eliminated using the SIC in the receiver side [12]. The channel capacity of the affected broadcast channels is improved using superposition coding and SIC [13]. The system maximizes interference because of the multi-user activity when the NOMA offers many transmission opportunities to the users [14]. Hence, power allocation is considered an essential issue used to achieve the full benefits of NOMA. The common principle in the NOMA is that the users with weak channel gains are assigned with a higher power, and the users with the substantial channel gains are assigned lesser power [15].

The contributions of this research are specified as follows:

- The NOMA network is developed with multiple users to improve communication.
- The sum rate of the NOMA network is improved by proposing the M-SRBOA based power allocation with multi-objective functions such as sum rate and Rayleigh fading coefficients.
- Additionally, an appropriate power allocation for all users in NOMA is used to minimize the outage probability.

The paper's overall organization of this paper is given as follows: Section 2 provides the information about the existing power allocation researches done in NOMA. The proposed M-SRBOA based power allocation for all users of NOMA is clearly described in section 3. Section 4 delivers the results and discussion of the M-SRBOA method. The conclusion of this research work is given in section 5.

2. Related work

This section provides information about existing research developed for power allocation in NOMA.

Wang and Zhao [16] developed the joint spectrum and resource allocation for NOMA enhanced relaying networks. Next, the subcarrier allocation was optimized using a simulated annealing approach with fixed power allocation. The subcarrier user allocation problem was improved using the search efficiency of the SA. However, an unwanted increment in the transmit power affects the system's performance. Wang [17] formulated the power allocation as a non-convex optimization issue for the multiple carriers of NOMA. The designed power allocation approach was considered the user's power order constraints for each subchannel and SIC error of the receivers. The weighted sum rate (WSR) was maximized with an increasing number of users according to the increment in the multi-user diversity gain. However, the WSR performance was decreased with increment SIC error. Baidas [18] presented the power allocation using signal-to interference-plus-noise ratio (SINR) for the downlink NOMA system. The different power allocation approaches used in the NOMA were proportional-fairness-SINR maximization, multi-objective SINR maximization max-min SINR, and sum-SINR maximization. An equal power allocation (EPA) was developed to analyze the various power allocation approaches. The users with appropriate channel conditions were increased sum of SINR of all users. But, the min-max SINR power allocation was less efficient, resulting in less SINR. Bhardwaj, Mishra, and Shankar [19] developed the OPA factors for the downlink NOMA of two users where the users were switched from weak to strong vice versa based on the channel gains. Moreover, the optimal power allocation was possible only when there was a high gain ratio. Agarwal and Jagannatham [20] presented the difference of convex optimization (DCO) to accomplish the power allocation for the NOMA users. This DCO was used to enhance the sum rate based on the power factors of the user and relay that incorporated the QoS constraints. The designed DCO was achieved improved power allocation than the fixed and random allocations. However, this work was considered only two users; it failed to process multiple users. Khaleel Ahmed and Venkateswara Rao [21] developed the salp particle swarm optimization for power allocation (SPPA) based power among the users of the NOMA. The bit error rate (BER) of SPPA was reduced along with the increment in users. However, the energy was less when the signal to noise ratio (SNR) was small in the NOMA system.

The problems found from the existing research papers are given as follows: The data transmission among the NOMA users is affected because of the blind increment in the user's transmit power [16]. Moreover, the increment in the successive interference cancellation error affects the weighted sum rate of the NOMA users [17]. For the better analysis of power allocation over the NOMA, the system should consider the multiple users. The DC-based power allocation [20] was considered only two users for accomplishing the data transmission. In order to overcome this, an optimal power is allocated using M-SRBOA to the users of the NOMA that results in high sum rate. Moreover, the superposition coding and SIC decoding are used to reduce the interference among the users of the NOMA network.

3. M-SRBOA method

In this research, an efficient power allocation for all users of the NOMA is done by the M-SRBOA which increases the sum rate. Here, the optimal power allocation is achieved by considering the sum rate and Rayleigh fading coefficients in the M-SRBOA. The main processes of the M-SRBOA are QPSK modulation, power allocation, superposition coding, data symbol transmission through the channel, SIC decoding, and QPSK demodulation. The block diagram of the M-SRBOA method is illustrated in Fig. 1.

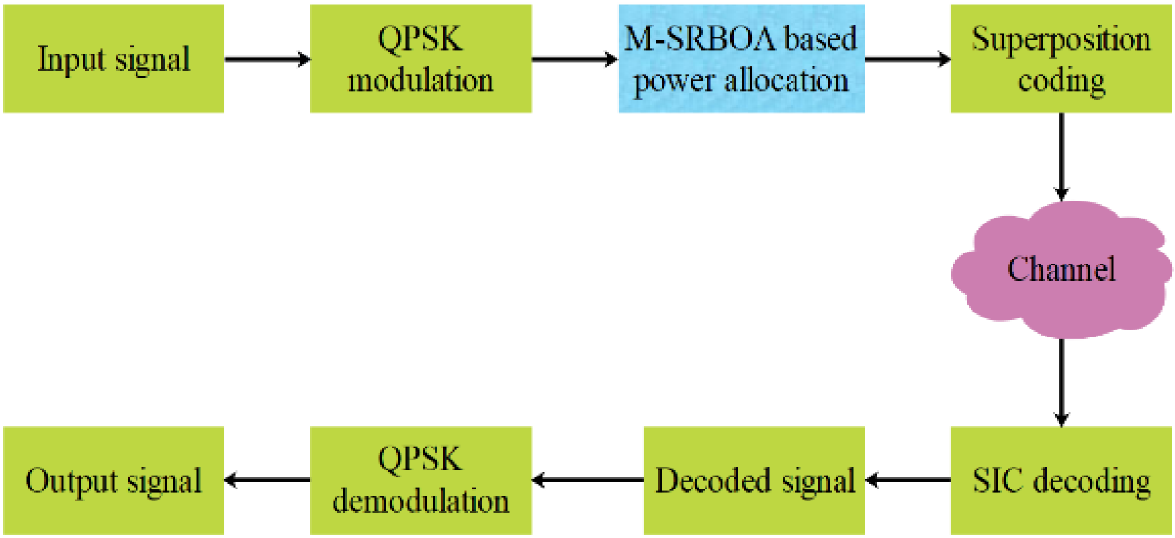

Figure. 1 Block diagram of the M-SRBOA method

The significant steps of the M-SRBOA method are given as follows:

Step 1: In this M-SRBOA method, three NOMA users are considered in the topology for accomplishing the communication. Consider, three users are placed in the topology with different distances. The channel model considered in this NOMA system is the Rayleigh fading model.

Step 2: Initially, quadrature phase shift keying (QPSK) is used to modulate the input signal.

Step 3: An optimal power allocation is required for all three users of NOMA. According to the principles of NOMA, the weakest user must be allocated with high power, and the most robust user must be allocated with the least power. In this research, an M-SRBOA is used to allocate the optimal power to the users. The power allocation is optimized by considering the distinct objective functions such as sum rate and Rayleigh fading coefficients.

Step 4: After allocating the power to each user in the NOMA system, the superposition coding is performed on the transmitter side. Next, the transmit signal is broadcasted over the Rayleigh fading channel model.

Step 5: The SIC is accomplished on the receiver side, where the transmit signal of each user is decoded that used to avoid interferences. The NOMA supports numerous users for sharing the same spectrum resource based on superposition coding and SIC.

Step 6: After decoding the received signals, the signal is demodulated to acquire the output signal.

Step 7: Whole performance of the proposed method is analyzed by validating the output signal with the input signal.

3.1 System model

In M-SRBOA, a downlink NOMA network is assumed with one base station (BS) and N amount of network users which are represented as $U_i, i \in \{1,2, \dots, N\}$, where the maximum value of N is equal to 3. Here, were the BS communicated with the N amount of data symbols $x_{,i}$ to the particular users U_i through the broadcast channel. The QPSK based data modulation and demodulation were performed in the transmitter and receiver side of the NOMA respectively. The Rayleigh fading with zero mean N_0 -variance of additive white Gaussian noise (AWGN) is considered as a rapid channel among the users and BS. Moreover, the coefficient of channel among the user U_i and BS is denoted as h_i and zero-mean complex Gaussian random variable with a variance of σ_i^2 in the NOMA network. The channel gains $|h_i|^2$ of the NOMA are the exponential random variables with discrete rates $\lambda_i \triangleq 1/\sigma_i^2, \forall i \in \{1, 2, \dots, N\}$.

The data symbols of all users of the NOMA are concurrently transmitted by the BS using the superposition coding. Eq. (1) expresses the signal received in the user U_j.

$$y_j = h_j \sum_{i=1}^{N} \sqrt{a_i P} x_i + \eta_j \quad (1)$$

Where, the power allocation coefficient of user i is represented as a_i i.e., $\sum_{i=1}^{N} a_i \leq 1$; total transmit power in the BS is denoted as P and the noise is represented as η_j. Subsequently, the channel gains are sorted in ascending order i.e., $0 < \left|h_{(1)}\right|^2 < \cdots <$

$|h_{(N)}|^2$ that specifies the $a_{(1)} > \cdots > a_{(N)}$. The data symbol of the users is decoded by applying the SIC in the receiver. Besides, the remaining users are treated with best channel conditions as interference i.e., no user decodes the data symbols of any other strong users. The SINR in the n^{th} user with perfect SIC is used for detecting its data. The SINR $\gamma_{(n)}$ for the user, n is expressed in the Eq. (2).

$$\gamma_{(n)} = \frac{\rho|h_{(N)}|^2 a_{(n)}}{\rho|h_{(N)}|^2 \bar{a}_{(n)}+1} \tag{2}$$

Where $\rho \triangleq P/N_0$ and $\bar{a}_{(n)} = \sum_{i=n+1}^{N} a_{(i)}$. Eq. (3) shows the SNR of the user with order N when the respective user decodes their data.

$$\gamma_{(N)} = \rho|h_{(N)}|^2 a_{(N)} \tag{3}$$

An optimal power allocation coefficient a_i of the NOMA network is identified using the M-SRBOA. The sample architecture of NOMA is shown in Fig. 2.

3.2 Power allocation using M-SRBOA

In this research, the proposed M-SRBOA is used to perform an effective power allocation by discovering appropriate power allocation coefficients. Generally, the butterfly optimization algorithm (BOA) replicates the food searching and mating behavior of the butterfly. The fragrance discharged by the other butterflies defines the attraction of the butterflies between each other. Here, the butterfly's movement is either in the butterfly that discharges high fragrance or in a random manner. In common, the objective function of the BOA is stimulus intensity. On the contrary, the multiple objective functions considered in the M-SRBOA are sum rate and Rayleigh channel fading coefficients. The iterative phase and objective function formulation for the M-SRBOA are explained in the following section.

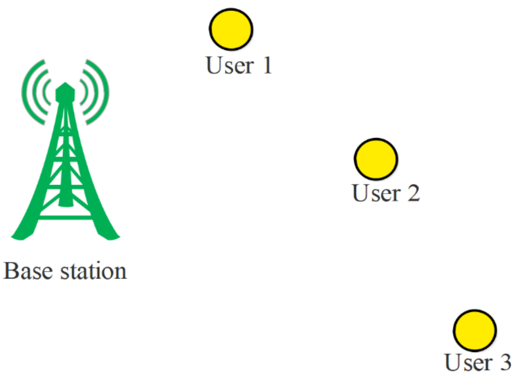

Figure. 2 Architecture of NOMA

3.2.1. Iterative phase

Initially, the power allocation coefficients of all users of the NOMA network are randomly initialized based on the distance between the users and BS. The butterfly's location is updated either in a global or in local search phase which mainly depends on the random number generated among [0, 1]. Since the location of the butterfly is enhanced according to the discharged fragrance emitted by the other butterflies. Eq. (4) shows the generated fragrance for the butterflies according to a certain location.

$$f = cI^b \tag{4}$$

Where, the fragrance is represented as f; sensory modality is denoted as c; stimulus intensity and power exponent are characterized as I and b respectively. Moreover, the global and local search phases are considered as an essential step of the BOA. In the global search phase, the butterfly is moved according to the optimal butterfly or solution g^* whereas the following Eq. (5) expresses the solution vector of the global search phase.

$$z_i^{t+1} = z_i^t + \left(r^2 \times g^* - z_i^t\right) \times f_i \tag{5}$$

Where, the solution vector for butterfly i in iteration t is denoted as z_i^t; r defines the random value created between $[0, 1]$ and fragrance of butterfly i is f_i. The solution discovered as best between all solutions of the current iteration is represented as g^*.

Eq. (6) shows the solution vector of the local search phase.

$$z_i^{t+1} = z_i^t + \left(r^2 \times z_j^t - z_k^t\right) \times f_i \tag{6}$$

Where, the z_j^t and z_k^t denotes the butterfly j and k at iteration t. Moreover, the above Eq. (6) is turned into local random, when both the z_j^t and z_k^t are from the same butterfly.

3.2.2. Objective function formulation

The multiple objectives considered in M-SRBOA are sum rate and Rayleigh channel fading coefficients. These objectives are used to obtain an appropriate power allocation coefficient for the users which helps increase the sum rate and minimizes the loss. The objective functions are formulated as follows:

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a. Sum rate

The sum rate of the NOMA network is expressed in the following Eq. (7).

$$SR\ (N) = \log_2(1 + \rho|h_{(N)}|^2 a_{(N)}) \quad (7)$$

b. Rayleigh channel fading coefficient

Generally, the Rayleigh channel fading coefficient is inversely proportional to the distance among the users and BS (d). Since, the power is allocated based on the weak and strong user which is defined according to the distance between the users and BS.

$$h_N = q_N d_N^{-\frac{\alpha}{2}} \quad (8)$$

Where, $q_N \sim CN(0,1)$, CN defines the complex normal distribution, and the path loss exponent is denoted as α.

The aforementioned multiple objectives are considered as stimulus intensity for the M-SRBOA. The derived stimulus intensity is shown in the following Eq. (9).

$$I = SR(N) + h_N \quad (9)$$

The stimulus intensity of Eq. (9) is used in Eq. (4) to update the fragrance of the butterflies. Since, the M-SRBOA has mainly updated its location based on the discharged fragrance, it helps to achieve the best pairs of power allocation coefficients a_i for all users of the NOMA network. Accordingly, these a_i are assigned to each user of NOMA, then it resulted in a higher sum rate and less outage probability.

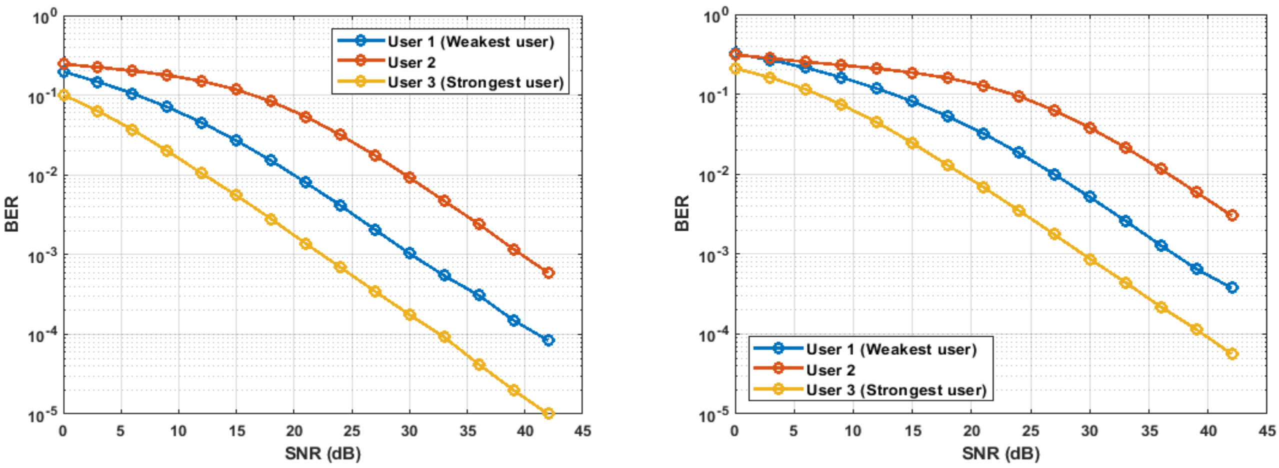
4. Results and discussion

The results and discussion of the M-SRBOA are given in this section. The implementation and simulation of this M-SRBOA method are done in the MATLAB R2018a software where the system runs with the i5 processor with 6GB RAM. The main objective of this M-SRBOA is to achieve a higher sum rate and less outage probability by accomplishing an appropriate power allocation. Here, the NOMA network is simulated with the 3 users communicated over the Rayleigh fading channel.

4.1 Performance analysis

The performance analyzed in this research are BER, achievable sum rate and outage probability. Here, the performance is analyzed with two different noise variance σ_i^2 values such as 2 and 10. The performance analysis for different noise variances are provided as follows:

Figs. 3, 4 and 5 show the performance analysis of the BER, achievable sum rate and outage probability respectively. Here, BER, achievable sum rate and outage probability are analyzed for two different noise variances such as 2 and 10. Next, Table 1 provides the comparison of the BER, and Table 2 provides the comparison of achievable sum rate and outage probability for different σ_i^2 values. From the BER analysis, it is known that the BER of User 3 (i.e., strongest user) is less when compared to the other users. The M-SRBOA with noise variance $\sigma_i^2 = 2$ achieves a higher achievable sum rate and less outage probability than the M-SRBOA with noise variance $\sigma_i^2 = 10$. The sum rate of the M-SRBOA with noise variance $\sigma_i^2 = 2$ varies in the range of 8.13 to 22.06 bps/Hz whereas the sum rate of the M-SRBOA with noise variance $\sigma_i^2 = 10$ varies in the



(a) (b)

Figure. 3 Analysis of BER: (a) For $\sigma_i^2 = 2$ and (b) For $\sigma_i^2 = 10$

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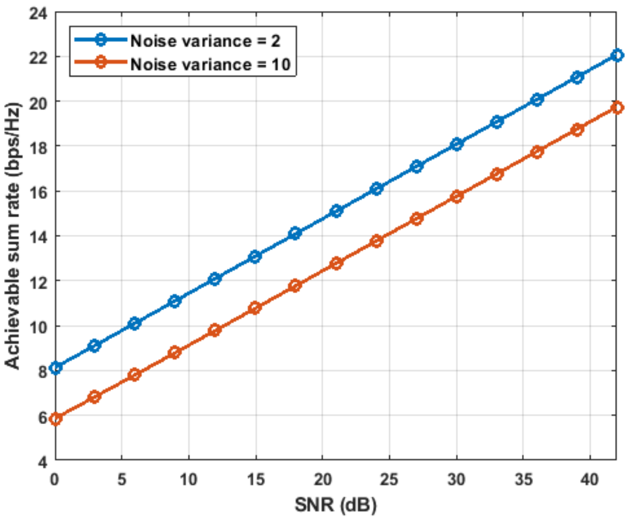

Figure. 4 Analysis of achievable sum rate

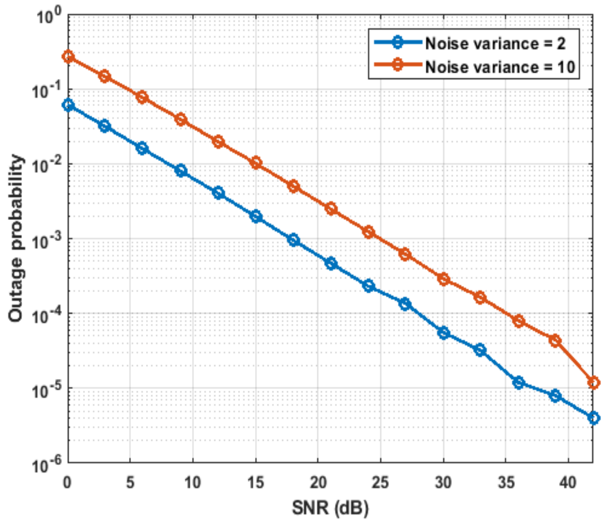

Figure. 5 Analysis of outage probability

Table 1. BER of M-SRBOA method

SNR (dB)	$\sigma_i^2 = 2$			$\sigma_i^2 = 10$		
	User 1	**User 2**	**User 3**	**User 1**	**User 2**	**User 3**
0	0.1970	0.2461	0.1006	0.3220	0.3133	0.2105
3	0.1469	0.2241	0.0633	0.2693	0.2812	0.1622
6	0.1053	0.2025	0.0369	0.2145	0.2541	0.1149
9	0.0713	0.1783	0.0200	0.1626	0.2313	0.0744
12	0.0453	0.1497	0.0104	0.1181	0.2098	0.0446
15	0.0270	0.1173	0.0055	0.0814	0.1865	0.0246
18	0.0151	0.0836	0.0028	0.0529	0.1597	0.0129
21	0.0080	0.0539	0.0014	0.0322	0.1283	0.0069
24	0.0041	0.0317	6.9400×10^{-4}	0.0184	0.0946	0.0035
27	0.0021	0.0176	3.4600×10^{-4}	0.0099	0.0628	0.0018
30	0.0010	0.0092	1.7600×10^{-4}	0.0052	0.0380	8.6800×10^{-4}
33	5.4400×10^{-4}	0.0047	9.2000×10^{-5}	0.0026	0.0216	4.4200×10^{-4}
36	3.0800×10^{-4}	0.0024	4.2000×10^{-5}	0.0013	0.0116	2.1800×10^{-4}
39	1.5000×10^{-4}	0.0012	2.0000×10^{-5}	6.5200×10^{-4}	0.0059	1.1400×10^{-4}
42	8.4000×10^{-4}	5.9200×10^{-4}	1.0000×10^{-5}	3.7600×10^{-4}	0.0030	5.6000×10^{-5}

Table 2. Achievable sum rate and outage probability of M-SRBOA method

SNR (dB)	**Achievable sum rate (bps/Hz)**		**Outage probability**	
	$\sigma_i^2 = 2$	$\sigma_i^2 = 10$	$\sigma_i^2 = 2$	$\sigma_i^2 = 10$
0	8.1314	5.8641	0.0614	0.2704
3	9.1193	6.8287	0.0315	0.1460
6	10.1110	7.8068	0.0158	0.0761
9	11.1049	8.7928	0.0080	0.0392
12	12.1000	9.7835	0.0040	0.0198
15	13.0957	10.7768	0.0020	0.0101
18	14.0919	11.7716	9.5600×10^{-4}	0.0050
21	15.0882	12.7672	4.7200×10^{-4}	0.0025
24	16.0847	13.7632	2.3200×10^{-4}	0.0012
27	17.0812	14.7595	1.3600×10^{-4}	6.2000×10^{-4}
30	18.0778	15.7560	5.6000×10^{-5}	2.9200×10^{-4}
33	19.0743	16.7525	3.2000×10^{-5}	1.6400×10^{-4}
36	20.0709	17.7490	1.2000×10^{-5}	8.0000×10^{-5}
39	21.0675	18.7456	8.0000×10^{-6}	4.4000×10^{-5}
42	22.0640	19.7421	4.0000×10^{-5}	1.2000×10^{-5}

Table 3. Comparative analysis of the M-SRBOA

SNR (dB)	Achievable sum rate (bps/Hz)					
	EPA [18]	OPA [19]	$\sigma_i^2 = 2$		$\sigma_i^2 = 10$	
			DCO [20]	M-SRBOA	DCO [20]	M-SRBOA
15	3.25	9	2.9	13.0957	3.6	10.7768
18	NA	10	3.25	14.0919	4.2	11.7716
21	NA	11	3.7	15.0882	4.65	12.7672
24	NA	12	4.2	16.0847	5.2	13.7632
27	NA	13	4.7	17.0812	5.75	14.7595
30	8	14	5.1	18.0778	6.2	15.7560

range of 5.86 to 19.74 bps/Hz. Moreover, the outage probability for $\sigma_i^2 = 2$ varies in the range of 0.0614 to 4.0000×10-6 whereas the outage probability for $\sigma_i^2 = 10$ varies in the range of 0.2704 to 1.2000×10-5.

4.2 Comparative analysis

This section shows the comparative analysis of the M-SRBOA in terms of achievable sum rate. The existing researches such as EPA [18], OPA [19], and DCO [20] are used to evaluate the efficiency of the M-SRBOA method.

Table 3 provides the performance comparison of the achievable sum rate for M-SRBOA with EPA [18], OPA [19], and DCO [20]. From Table 2, it is concluded that the M-SRBOA method achieves a higher achievable sum rate than the EPA [18], OPA [19], and DCO [20]. For example, the achievable sum rate of M-SRBOA for the SNR of 30 dB with $\sigma_i^2 = 2$ is 18.07 bps/Hz, which is high when compared to the EPA [18], OPA [19], and DCO [20]. The M-SRBOA with an appropriate objective function is used to allocate an optimal power to the NOMA users that resulted in a higher achievable sum rate. Here, the NOMA network is developed with multiple users. Since, the interference among the users are minimized by using the superposition coding and SIC decoding in NOMA network.

5. Conclusion

In this paper, the M-SRBOA method is developed for allocating power to all users of the NOMA network. The multiple objective functions such as sum rate and Rayleigh fading coefficients considered in the M-SRBOA are used to accomplish an effective power allocation to the users. This M-SRBOA based power allocation for all users of NOMA is used to enhance the performances of achievable sum rate and outage probability. Moreover, the combination of superposition coding and SIC decoding is used to minimize the interference among the users in the NOMA network. From the performance analysis, it is concluded that the M-SRBOA method provides better performance than the EPA, OPA and DCO. The achievable sum rate of M-SRBOA for the SNR of 15 dB with noise variance of 2 is 13.09 bps/Hz, which is high when compared to the EPA, OPA and DCO. In future, the novel optimization algorithm can be used for performing an effective power allocation over the NOMA network.

Conflicts of interest

The authors declare no conflict of interest.

Author contributions

The paper conceptualization, methodology, software, validation, formal analysis, investigation, resources, data curation, writing—original draft preparation, writing—review and editing, visualization, have been done by 1st author. The supervision and project administration, have been done by 2nd author.

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